EBAF Update

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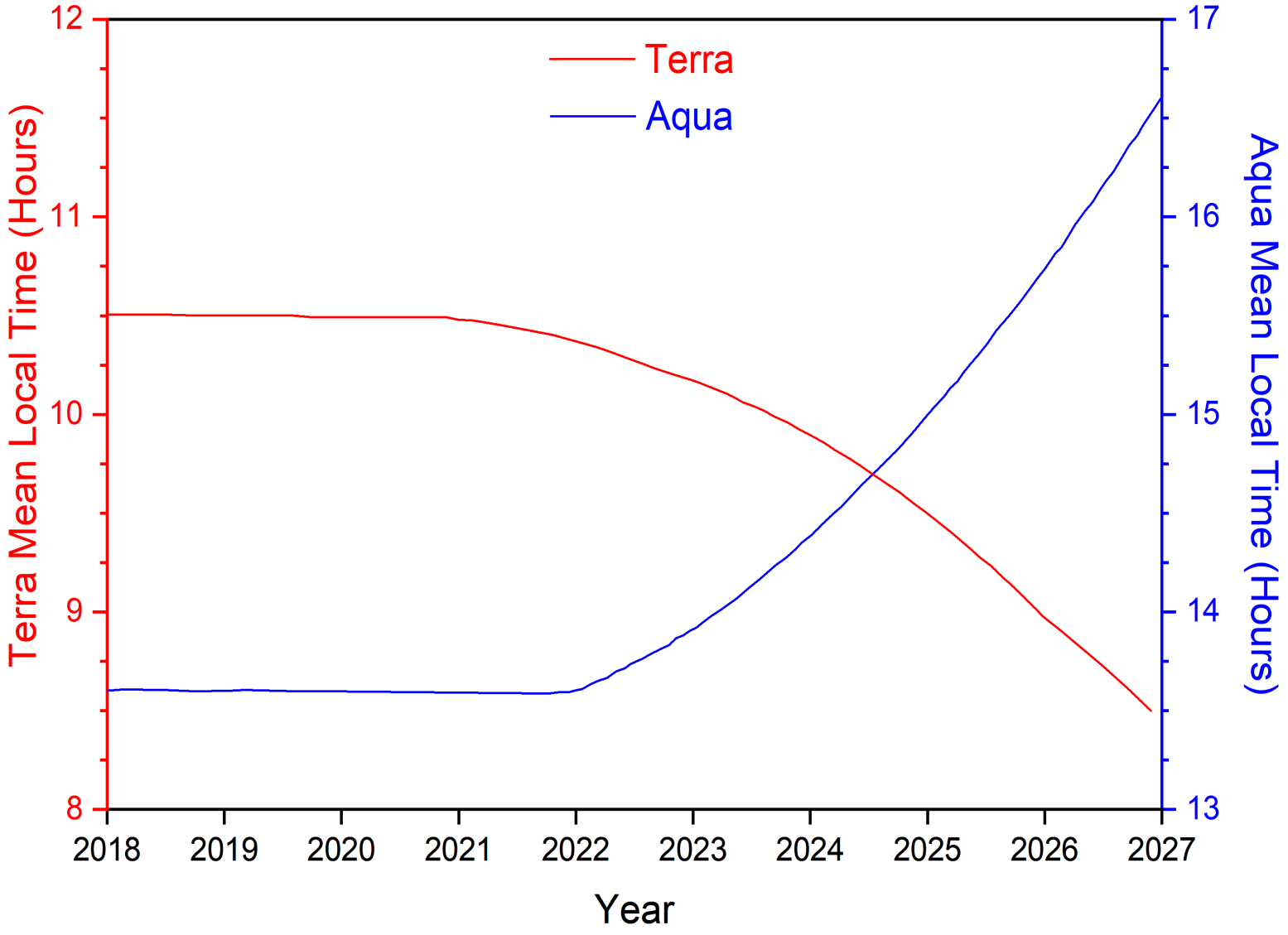
Virtual Meeting

Background

- CERES EBAF leverages other CERES data products to provide a spatially and temporally complete representation of ERB. Advances include:
  - One-time adjustment within uncertainty to SW and LW fluxes such that 10-year mean (2005-2015) EEI is consistent with EEI determined from in-situ data (mainly Argo).
  - SW diurnal correction methodology that overcomes GEO artifacts.
  - Clear-sky “filling” with imager to avoid gaps in clear-sky maps.
  - Determination of clear-sky for total region, consistent with GCM definition.
  - Objective “tuning” of input variables used in Langley Fu-Liou to determine surface fluxes constrained by EBAF TOA fluxes.
- Currently uses only Terra and Aqua data, whose equator crossing mean local times (MLTs) have been maintained as close as possible to 1030 for Terra and 1330 for Aqua.
- However, Terra’s MLT will start to drift in January 2021 and Aqua’s MLT will start to drift in March 2022.

Mean Local Time of Equator Crossing for Terra's Descending and Aqua's Ascending Nodes



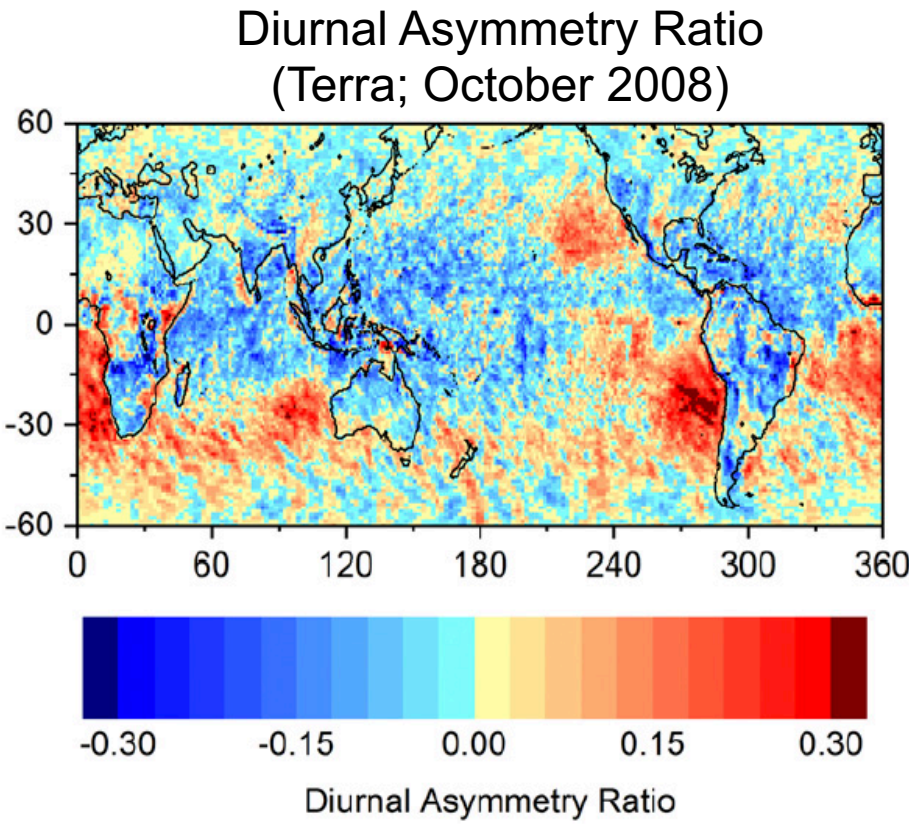
EBAF SW Empirical Diurnal Correction: Methodology

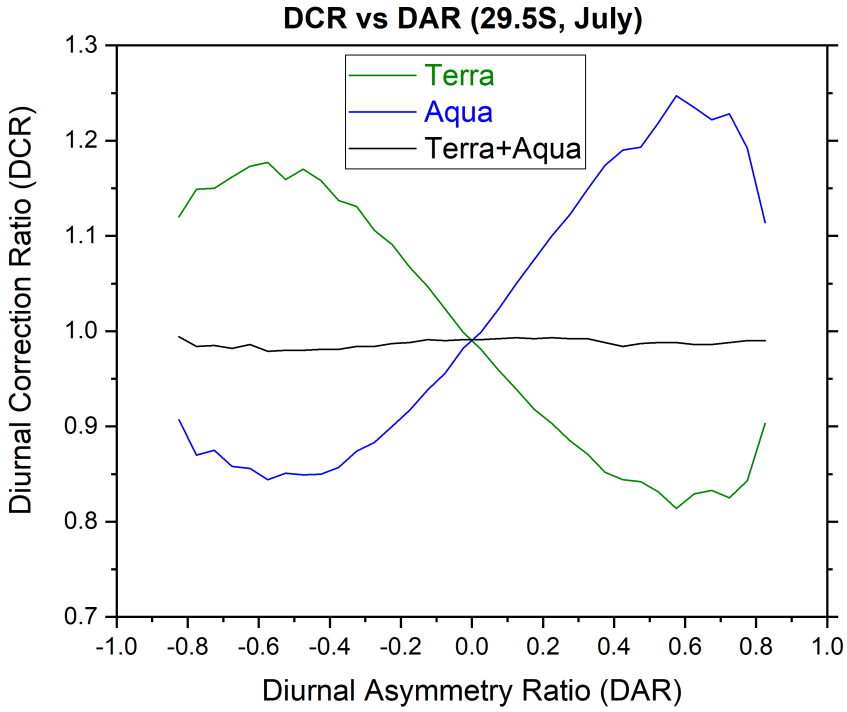
- Objective: Maintain the excellent calibration stability of CERES SSF1deg while at the same time preserving the diurnal information in SYN1deg without GEO artifacts.
- Approach: Apply pre-determined empirical diurnal corrections to daily mean regional SSF1deg SW fluxes over the GEO area of coverage (60S-60N) and average over each month.
- Diurnal corrections: Consist of diurnal correction ratios (DCRs), where DCR = SYN1deg-to-SSF1deg flux ratios, derived from daily mean SW TOA fluxes between July 2002 and June 2015.
- The DCRs are stratified according to calendar month, surface type, latitude, and a daily Diurnal Asymmetry Ratio (DAR), defined as:

$$DAR = \frac{F^{SW}(morn) - F^{SW}(aft)}{F^{SW}(24h)}$$

- F^{SW}(morn), F^{SW}(aft), F^{SW}(24h) are GEO-based mean SW flux for 0-12 h local time, 12-24 h LT and 0-24 h LT.

EBAF SW Empirical Diurnal Correction





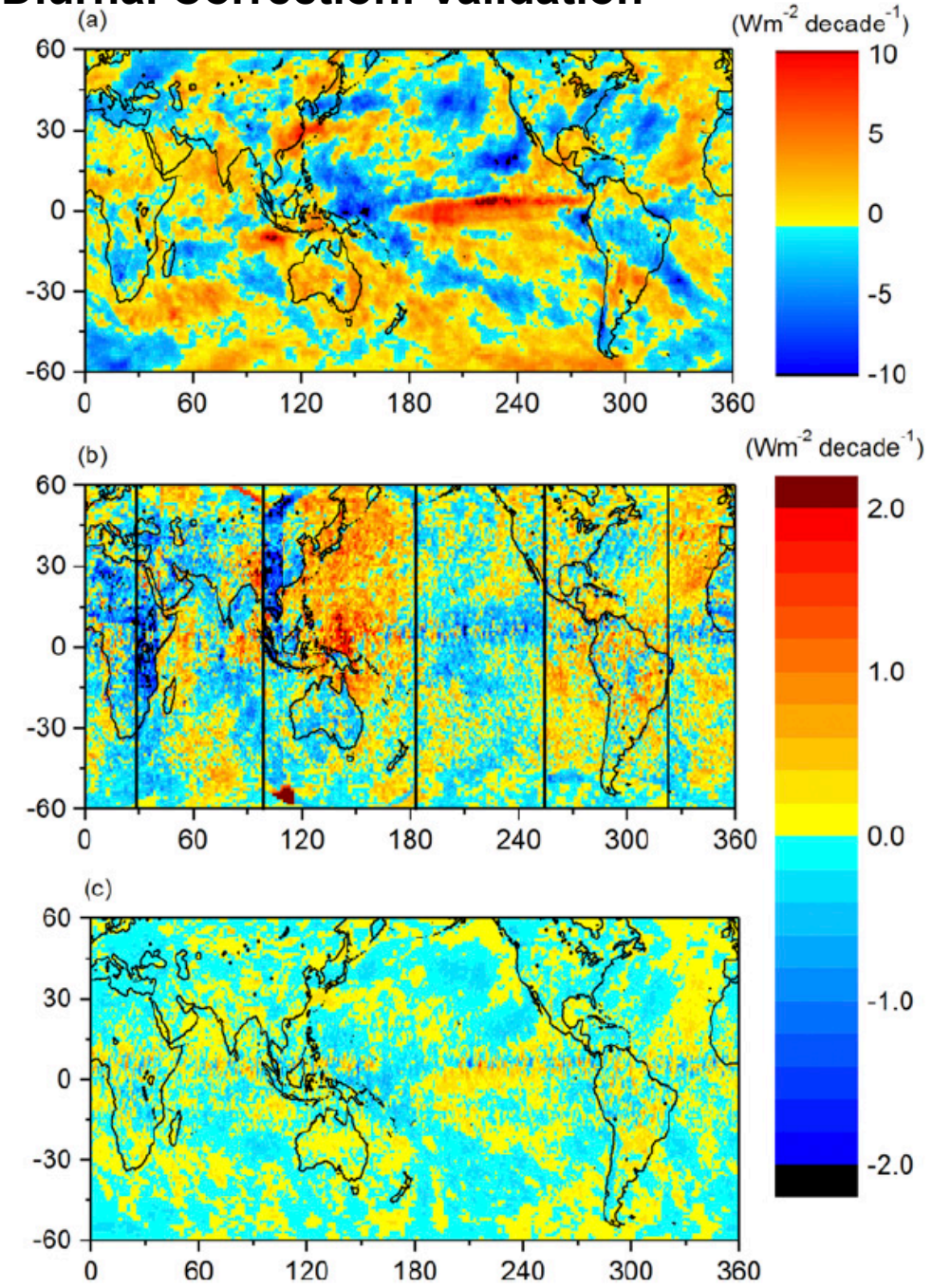
(Loeb et al., 2018)

EBAF SW Empirical Diurnal Correction: Validation

Trend in SW TOA flux anomalies from SSF1deg-Terra–Aqua for July 2002–September 2016

<u>SW Trend difference</u>: SYN1deg-Terra–Aqua minus SSF1deg-Terra–Aqua

<u>SW Trend difference</u>: EBAF minus SSF1deg-Terra–Aqua



EBAF After Terra & Aqua Begin to Drift in MLT

- After the Terra and Aqua start to drift in MLT, the diurnal corrections used in EBAF will no longer be applicable, as they were determined for fixed 1030 and 1330 Terra and Aqua MLTs.
- While the remaining CERES instruments aboard S-NPP and NOAA-20 are in afternoon orbits with MLTs close to Aqua's 1330 MLT, there is no plan for a future ERB instrument in a morning orbit.

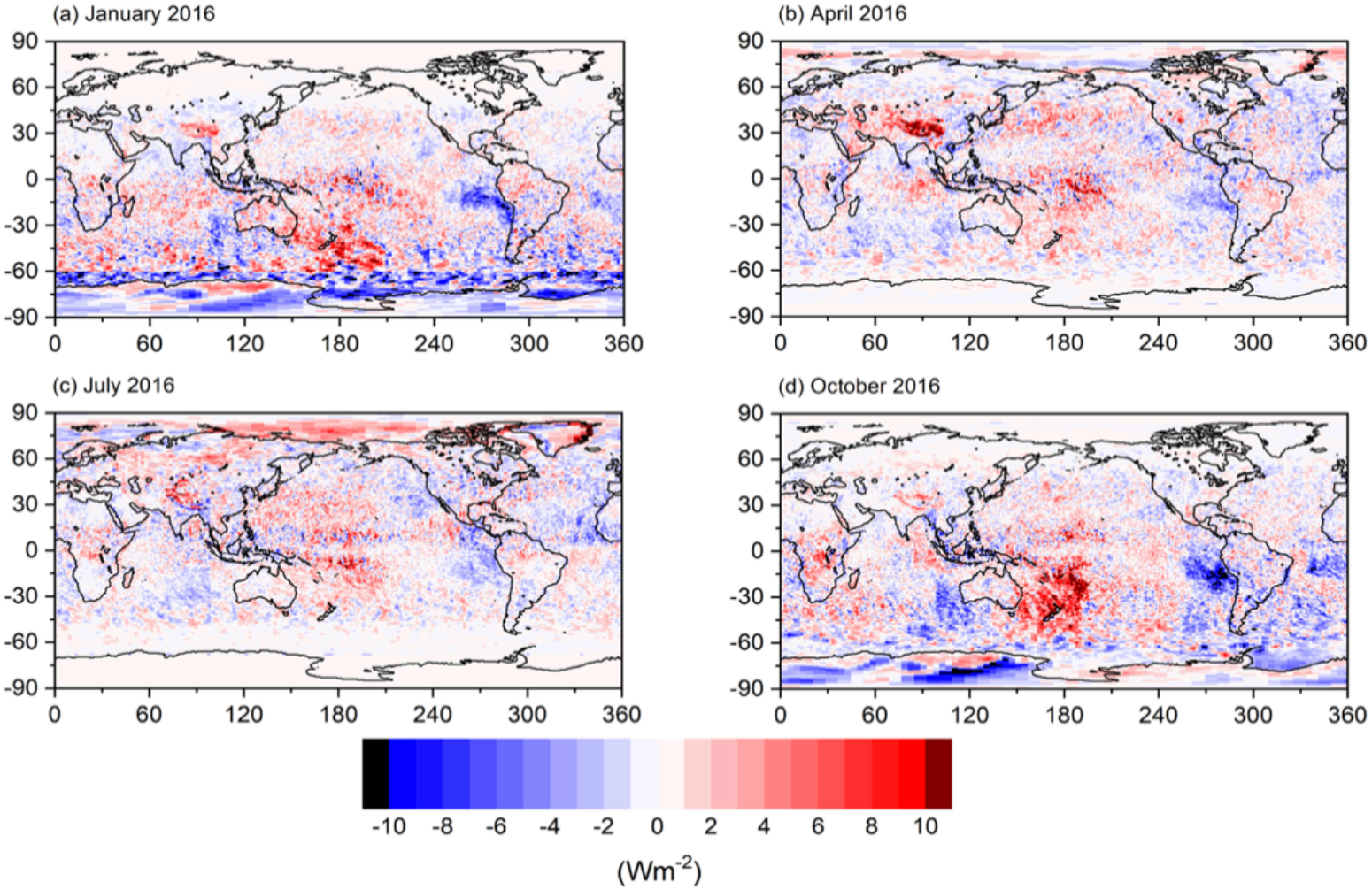
=> A different strategy for generating a stable, long-term CERES EBAF CDR is needed.

EBAF After Terra & Aqua Begin to Drift in MLT

Option 1: Keep existing Terra+Aqua EBAF through 01/2021 (when Terra starts to drift) and continue with afternoon satellites

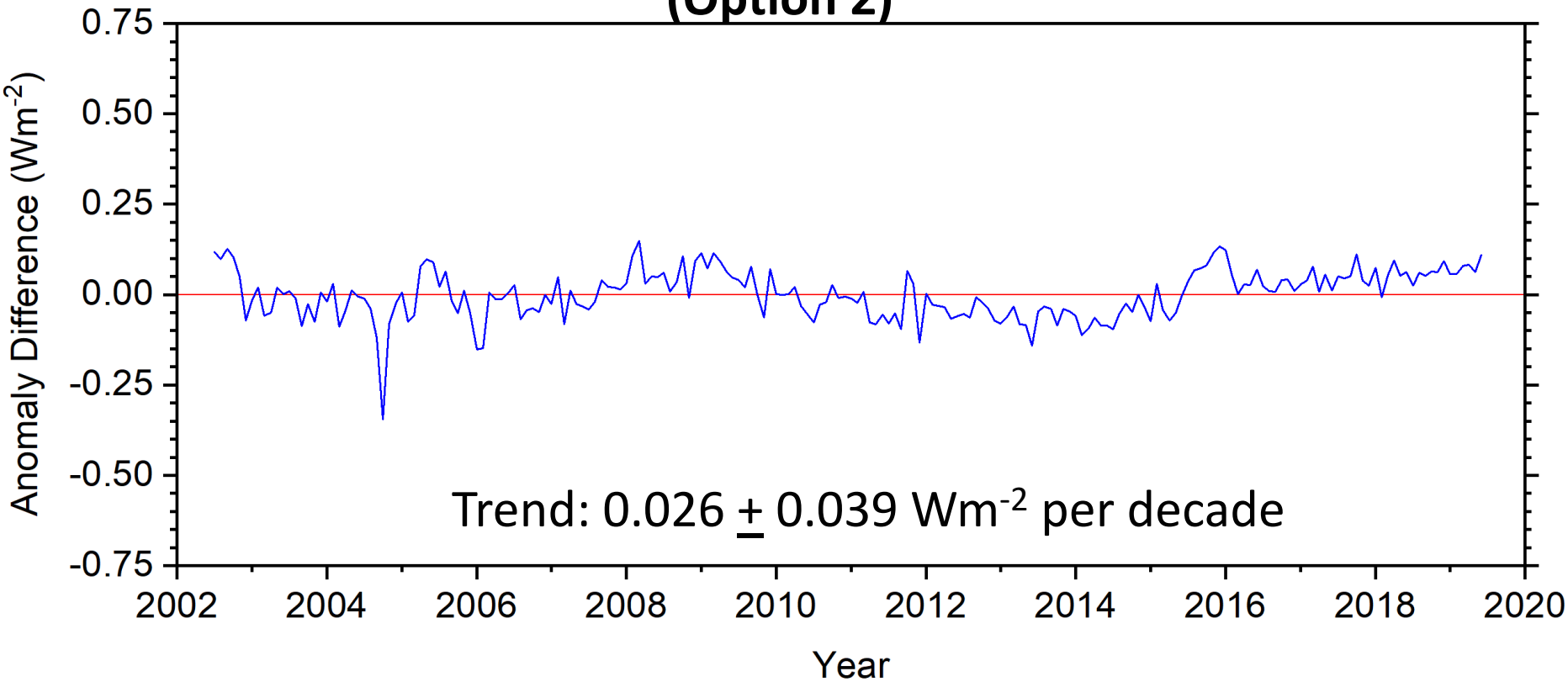
Option 2: Reprocess EBAF with Terra through 06/2002 followed by fixed MLT afternoon satellites

SW TOA Flux Difference: Aqua-Only minus Terra+Aqua
(SSF1deg with Diurnal Corrections Applied)



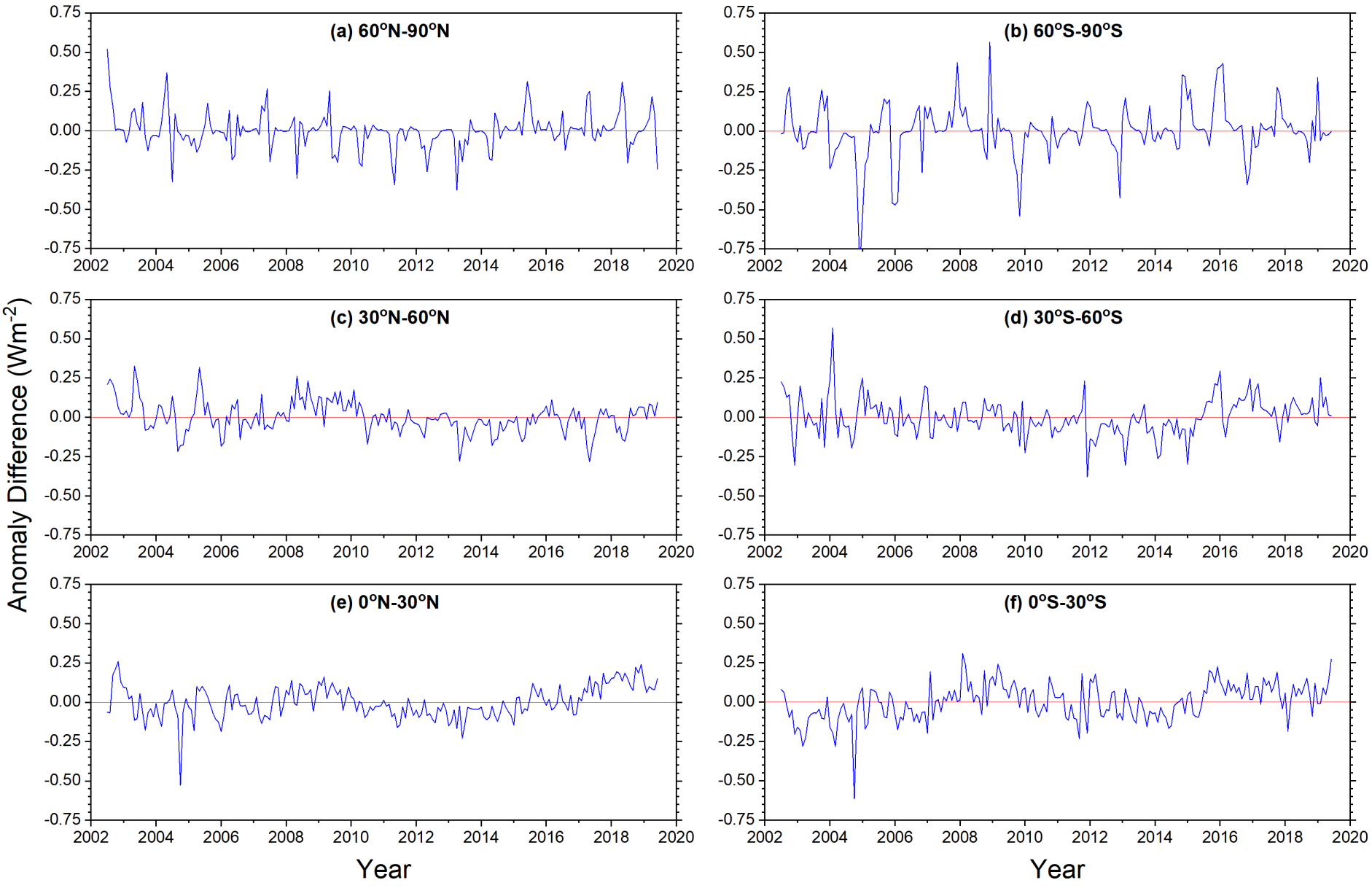
- Continuing existing Terra+Aqua EBAF with afternoon-only satellite (Option 1) will result in regional discontinuities.
- Large differences near International date line due to a recently discovered problem with the DAR calculation.

Aqua-only minus Terra+Aqua Monthly Global Anomaly Difference (Option 2)



(Loeb and Doelling, 2020)

Aqua-only minus Terra+Aqua Monthly Global Anomaly Difference (Option 2)



(Loeb and Doelling, 2020)

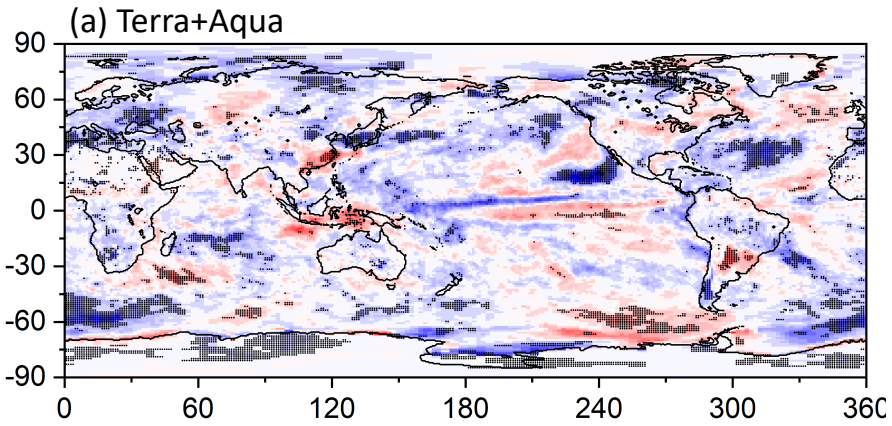
SW TOA Flux Variability & Trends (Aqua-Only vs Terra+Aqua Diurnal Correction)

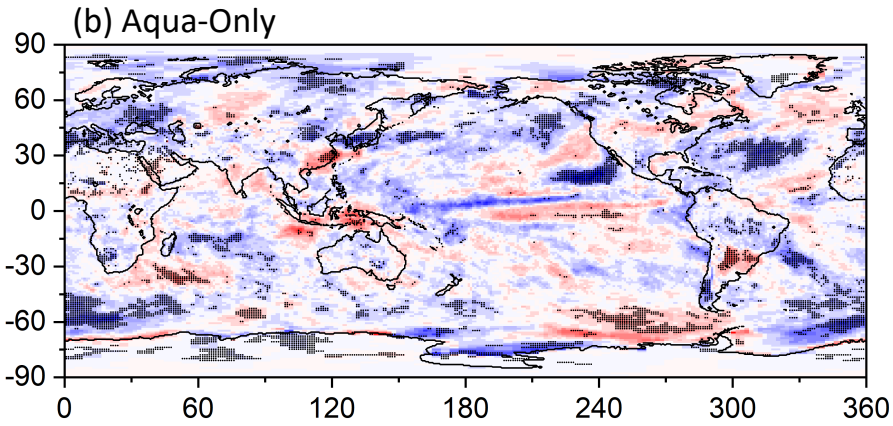
Table 2. Standard deviation, explained variance and trend in monthly SW TOA flux anomalies (Wm^{-2}) after applying DCR corrections for Terra + Aqua and for the difference between anomalies in Aqua-only and Terra + Aqua for 07/2002–06/2019. Trend uncertainty corresponds to 95% confidence interval.

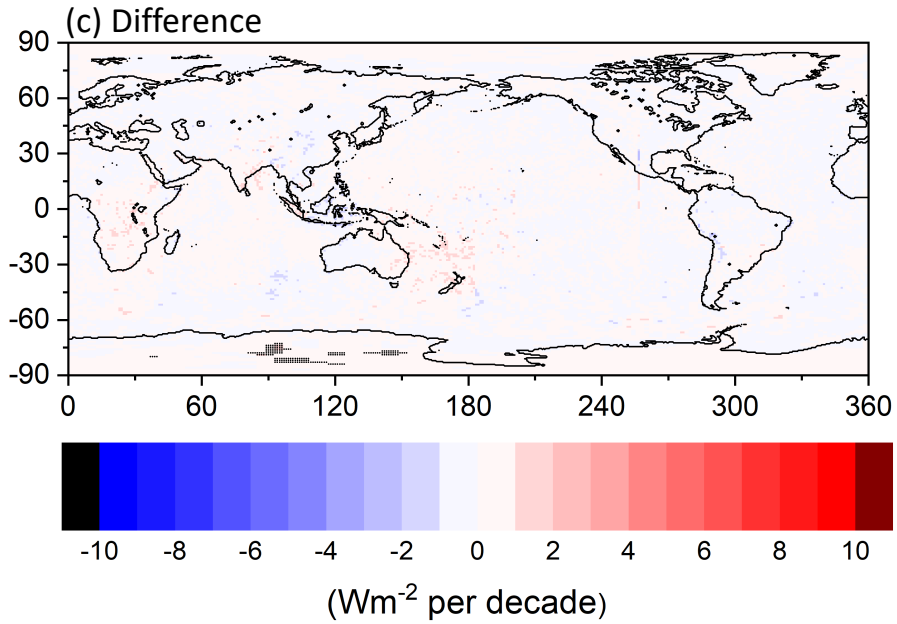
	Standard Deviation (Wm^{-2})		Explained Variance (%)	Trend (Wm^{-2} per Decade)	
Domain	**Ter + Aqu**	**Aqu − (Ter + Aqu)**		**Ter + Aqu**	**Aqu − (Ter + Aqu)**
60°N–90°N	1.86	0.12	99.6	−0.78 ± 0.85	−0.007 ± 0.047
30°N–60°N	1.33	0.10	99.4	−0.94 ± 0.40	−0.054 ± 0.054
0°–30°N	1.45	0.10	99.5	−0.53 ± 0.62	0.048 ± 0.056
0°–30°S	1.26	0.12	99.1	−0.38 ± 0.46	0.085 ± 0.047
30°S–60°S	1.00	0.12	98.6	−0.48 ± 0.33	0.003 ± 0.052
60°S–90°S	1.56	0.17	98.8	−0.44 ± 0.97	0.043 ± 0.085
Global	0.59	0.07	98.7	−0.57 ± 0.20	0.026 ± 0.039

(Loeb and Doelling, 2020)

SW TOA Flux Trend Comparison (07/2002-06/2019)







- Hatched areas in (a) and (b) correspond to trends that exceed 95% confidence interval.

- In (c), hatched areas correspond to trend differences that exceed 95% confidence interval in (a).

(Loeb and Doelling, 2020)

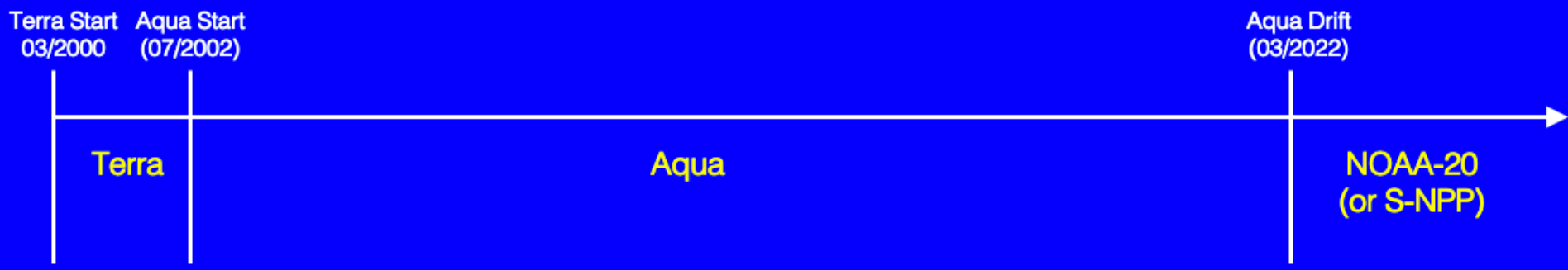
Aqua-Only minus Terra+Aqua SW TOA Flux Differences (07/2002-06/2019)

Month	Global Mean Bias	RMS of Regional	
		Climatological Monthly Mean Diff	Monthly Mean Diff
January	-0.18	1.8	2.6
April	0.09	1.3	2.1
July	0.08	1.1	1.9
October	-0.03	1.5	2.4

Conclusions

- Current EBAF is generated from CERES Terra & Aqua SSF1deg. It uses an empirical diurnal correction that avoids GEO artifacts.
- However, Terra's MLT will start to drift in 2021 and Aqua's MLT will start to drift in 2022.
- To maintain a stable ERB CDR after Terra and Aqua start to drift, the EBAF record will be reprocessed using only afternoon satellites with a tight 1330 MLT throughout.

Option 2: Reprocess EBAF with Terra through 06/2002 followed by fixed MLT afternoon satellites



- Variability and trends for afternoon-only EBAF consistent with current EBAF.
- Afternoon-only regional monthly mean consistent to 2.5 Wm^{-2} (1σ) with current EBAF. Overall uncertainty increases to 3.5 Wm^{-2}.

Backup Slides

Large Differences Near International Date Line

GMT	GMT	Local		Local		GMT	GMT	Local		Local
17-Mar	0	14		16-Mar		17-Mar	0	14		16-Mar
17-Mar	1	15		16-Mar		17-Mar	1	15		16-Mar
17-Mar	2	16		16-Mar		17-Mar	2	16		16-Mar
17-Mar	3	17		16-Mar		17-Mar	3	17		16-Mar
17-Mar	4	18		16-Mar		17-Mar	4	18		16-Mar
17-Mar	5	19		16-Mar		17-Mar	5	19		16-Mar
17-Mar	6	20		16-Mar		17-Mar	6	20		16-Mar
17-Mar	7	21		16-Mar		17-Mar	7	21		16-Mar
17-Mar	8	22		16-Mar		17-Mar	8	22		16-Mar
17-Mar	9	23		16-Mar		17-Mar	9	23		16-Mar
17-Mar	**10**	**0**	**LOCAL MIDNIGHT**	**17-Mar**		**17-Mar**	**10**	**0**	**LOCAL MIDNIGHT**	**17-Mar**
17-Mar	11	1		17-Mar		17-Mar	11	1		17-Mar
17-Mar	12	2		17-Mar		17-Mar	12	2		17-Mar
17-Mar	13	3		17-Mar		17-Mar	13	3		17-Mar
17-Mar	14	4		17-Mar		17-Mar	14	4		17-Mar
17-Mar	15	5		17-Mar		17-Mar	15	5		17-Mar
17-Mar	16	6		17-Mar		17-Mar	16	6		17-Mar
17-Mar	17	7		17-Mar		17-Mar	17	7		17-Mar
17-Mar	18	8		17-Mar		17-Mar	18	8		17-Mar
17-Mar	19	9		17-Mar		17-Mar	19	9		17-Mar
17-Mar	20	10		17-Mar		17-Mar	20	10		17-Mar
17-Mar	21	11		17-Mar		17-Mar	21	11		17-Mar
17-Mar	**22**	**12**	**LOCAL NOON**	**17-Mar**		**17-Mar**	**22**	**12**	**LOCAL NOON**	**17-Mar**
17-Mar	23	13		17-Mar		17-Mar	23	13		17-Mar
18-Mar	0	14		17-Mar		18-Mar	0	14		17-Mar
18-Mar	1	15		17-Mar		18-Mar	1	15		17-Mar
18-Mar	2	16		17-Mar		18-Mar	2	16		17-Mar
18-Mar	3	17		17-Mar		18-Mar	3	17		17-Mar
18-Mar	4	18		17-Mar		18-Mar	4	18		17-Mar
18-Mar	5	19		17-Mar		18-Mar	5	19		17-Mar
18-Mar	6	20		17-Mar		18-Mar	6	20		17-Mar
18-Mar	7	21		17-Mar		18-Mar	7	21		17-Mar
18-Mar	8	22		17-Mar		18-Mar	8	22		17-Mar
18-Mar	9	23		17-Mar		18-Mar	9	23		17-Mar
18-Mar	**10**	**0**	**LOCAL MIDNIGHT**	**18-Mar**		**18-Mar**	**10**	**0**	**LOCAL MIDNIGHT**	**18-Mar**
18-Mar	11	1		18-Mar		18-Mar	11	1		18-Mar

- DAR is derived from the difference between morning and afternoon SW TOA fluxes derived from GEO
- CERES uses Greenwich Mean Time (GMT) instead of local time (LT) to define a 24-h day (consistent with GCMs)
- Morning and afternoon are separated by nighttime on a 24-h GMT day at longitudes near the IDL
- Extreme DAR values can occur if cloud conditions change appreciably overnight
- This issue has a minimal effect for EBAF Ed4.1 since the DCRs are rather insensitive to DAR variations. Not true for Aqua-only.

Utility of Aqua & Terra After They Drift in MLT (Intercalibration)

- Extending Aqua enables continued intercalibration of CERES Aqua, SNPP and NOAA-20.
  - Since SNPP and NOAA-20 orbits are phased approximately 45-min apart and fly at the same altitude, it is not possible to directly compare these satellites.
  - Aqua's orbit is at a lower altitude with a similar mean local time, so the Aqua groundtrack crosses both SNPP and NOAA-20, enabling intercalibration.
  - Intercalibration plays a key role as it enables the CERES instrument team to verify that the calibration of each instrument is performing as expected.

Utility of Aqua & Terra After They Drift in MLT (Overlap with New Missions)

- Extending Terra and Aqua will enable overlap with the CLARREO-P, expected to fly on the International Space Station (ISS) in 2021.
  - Tremendous one-time opportunity to place all reflected solar bands from CERES, MODIS and VIIRS on all existing satellite platforms (Terra, Aqua, SNPP, NOAA-20 and possibly JPSS-2) on the same radiometric scale set by CLARREO-P.
  - Will dramatically improve the accuracy of climate data records from CERES, MODIS and VIIRS, impacting countless geophysical variables (radiative budget, aerosol, cloud, vegetation, etc.) back to 2000, the start of the Earth Observing System.
- Extending Aqua will also enable overlap with EarthCARE, expected to launch in 2022.
  - EarthCARE will fly in a sun-synchronous orbit with a 2 pm mean-local-time. The Aqua satellite is expected to have a 2 pm MLT in 2023, roughly one year after EarthCARE launches.
  - Since Aqua provided many years of coincident data with Cloudsat and CALIPSO (CC), also having Aqua measurements coincident with EarthCARE will provide a unique opportunity to assess the consistency of observations from CC and EarthCARE.
  - This will provide valuable information for studies that seek to use lidar and cloud radar retrievals from both CC and EarthCARE.

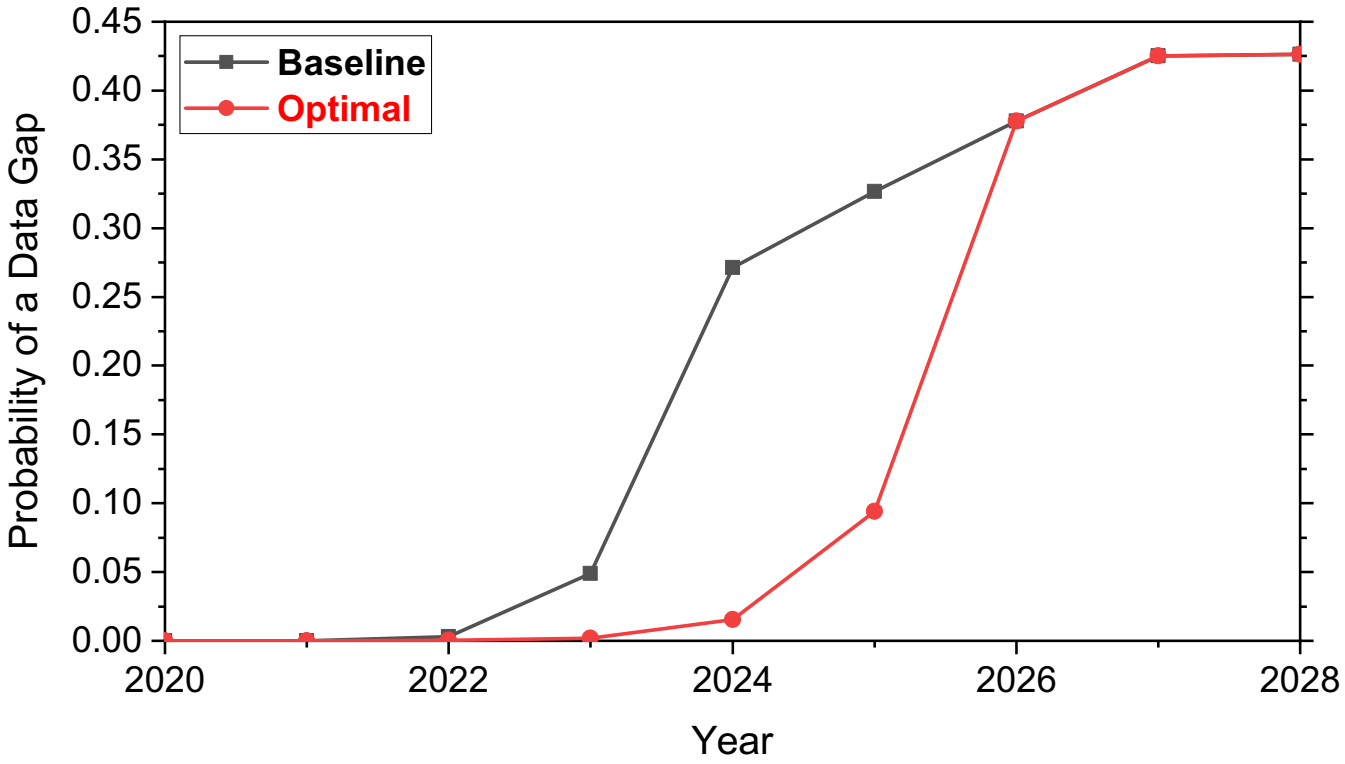
Utility of Aqua & Terra After They Drift in MLT (Improving Historical Satellite Record)

- Continuing Aqua after it starts to drift in MLT will enable highly accurate corrections to the historical satellite record dating back 40 years.
  - A major uncertainty in using the NOAA AVHRR record for producing long-term climate data records for a range of geophysical variables is orbital drift.
  - Having Aqua drift in MLT while SNPP and NOAA-20 are held at a fixed 1:30 pm MLT will enable algorithms that have been developed to correct for orbital drift in the historical record to be tested and improved using MODIS and VIIRS.
  - This will have a tremendous impact on the quality of 40-year records derived from AVHRR for a host of geophysical variables.

Utility of Aqua & Terra After They Drift in MLT (Extending the CERES ADMs)

- A slowly changing MLT for Terra will provide a unique opportunity to place one of the CERES instruments on Terra in a rotating azimuth plane (RAP) scan mode in order to extend the angular coverage of the CERES angular distribution models (ADMs) used to determine radiative fluxes from measured radiances.
  - In RAP mode, CERES scans in elevation as it rotates in azimuth, thereby acquiring radiances over a full hemispheric range of viewing zenith and relative azimuth angle combinations.
  - CERES RAP data acquired early in the Terra mission were used in order to construct CERES ADMs, which describe how TOA radiances normalized by flux vary with sun-Earth-satellite viewing geometry and scene type.
  - Once the Terra MLT starts to drift, the CERES team will place CERES FM2 in RAP mode. This will significantly expand the solar zenith angle coverage of the CERES ADMs and enable past and future missions in orbits that differ markedly from Terra to produce accurate radiative fluxes.
  - Over the past 15 years, the CERES ADMs have been a valuable community resource. Expanding the range of angular coverage will greatly increase their utility for many more groups interested in producing accurate radiation budget observations.

Probability of a Data Gap in ERB Climate Data Record



Launches	Deorbits
	Baseline: Aqua(2023); Terra(2022)
EVC (2027)	Optimal : Aqua(2025); Terra (2026)
	SNPP (2024); NOAA-20 (2029)

The Optimal scenario in which Aqua and Terra deorbit in 2025 and 2026 reduces the gap probability by a factor of 18 in 2024 (27% to 1.5%).